An Electronic Mesh phantom for planar structure EIS systems

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Background

There are two phantom types to assess EIT or EIS systems: physical and electronic phantoms. The physical phantom that is used for EIT or EIS systems typically is composed of a conductive saline solution or gel medium with objects embedded in this medium. The medium and object have different impedances, which permit the system to detect changes of impedance and image them. Physical phantoms have common problems of: short life, inflexibility, instability and uncontrollable physical characteristics. The E-phantom is used to assess the system characteristics of the EIT or EIS systems such as: current or voltage delivered, internal stray impedance and the effects of the impedance of the medium on the measurements. These results can then be used to optimise the electronic circuitry and components relevant to the impedance measurements to improve the performance of the system. Thus, the advantages of an E-phantom compared with a physical phantom are: improved quality, reproducibility, predictability and stability of signals. The Sussex EIS system is based on a planar 85-electrodes structure located at the bottom of the tank. Figure 1 shows planar 85-electrodes and 2D and 3D meshes of the system.

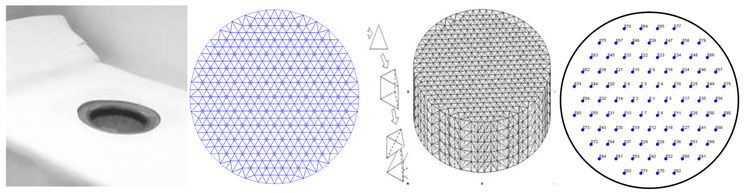


Figure 1. (a) Measurement tank 180 mm diameter inside the clinical bed, open top surface, 5 mm thick acrylic walls, (b) shows a 2D with electrode placements and 3D mesh of the saline tank with tetrahedral elements. The 3D tank and electrode structures are constructed in IR software to generate a homogenous phantom and (c) a planar 85-electrodes structure located at the bottom of the tank.

Objectives

Evaluation of planar EIT or EIS systems used in clinical studies can be based on a realistic electronic phantom (E-phantom). This poster describes a mesh phantom based on an 85 electrode planar mesh structure. The design presents a dynamic mesh phantom to assess the performance of the planar topology to simulate *in vivo* conditions. The Sussex EIS system is especially designed for breast cancer detection application for different breast sizes and shapes. It is fitted in a bed with the patient assessed whilst in a prone position. The phantom is especially designed for the Sussex EIS system to validate system performances i.e. SNR and modelling accuracy. The concept of the phantom here is to use a non-biological device to simulate a biological medium and giving similar biological behaviour.

Methods

Most of the research in the design of E-phantoms have focused on its application to the ring topology found in some EIT systems [1-3]. Similarly an E-phantom is designed to assess and validate the function of the Sussex EIT system. In order to design a mesh phantom for a planar electrode array with a homogeneous conductivity distribution (i.e. a saline solution), a FEM method has been applied. It uses discretization over the entire domain of the continuous conductive medium Ω. It works by dividing the domain into small sub-domains (elements). It then solves by developing the matrices of each element and gathering all elements with the compatibility and equilibrium conditions for the entire domain [4]. Thus the Laplace Eq.:

$$\nabla . \sigma . \nabla U = 0 \qquad (1)$$

$$F(U) = \frac{1}{2}\int_{\Omega} \sigma . \nabla U . \nabla U d\Omega \qquad (2)$$

Methods

$$\nabla U = U_i . \nabla \alpha_i \qquad (3)$$

$$F(U) = \frac{1}{2}\sigma U_i \int \nabla \alpha_i \nabla \alpha_j d\Omega \, U_j = \frac{1}{2} U^T Y_{ij} U \qquad (4)$$

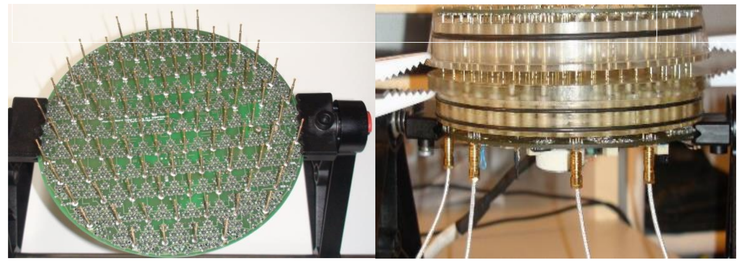


Figure 2. (a) shows the mesh phantom board (b) shows the direct connection between the EIT board at the bottom and the E-phantom board at the top through INGUN GKS-100 224 130A electrodes with internal resistance of less than 20mΩ.

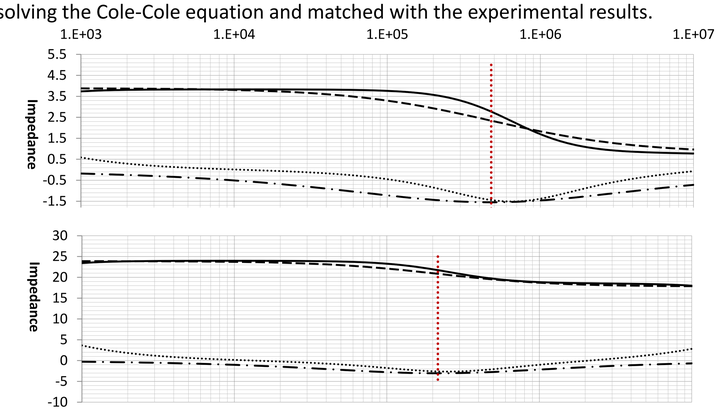
Therefore, FEM is used to calculate the conductivity of single element (Y_{ij}^e) in the matrix; then these elemental conductivity matrices are combined in a general matrix of conductivity (Y_{ij}). Finally, these conductivity elements are replaced by resistors with the same conductance. The PCB representing this matrix of homogenous medium with 85 planar-electrodes is shown in Figure 2(a). In addition, this E-phantom is capable of simulating biological items such as pieces of carcinoma, fat, and stroma tissues in a saline based solution based on using RSC circuit model (extra- and intracellular resistance and cell membrane capacitance) of tissues. A saline conductivity of 0.5mS/cm has been used as the homogeneous medium in order to give a low impedance connection from sensor electrodes to the breast target as *in viva* condition.

Results

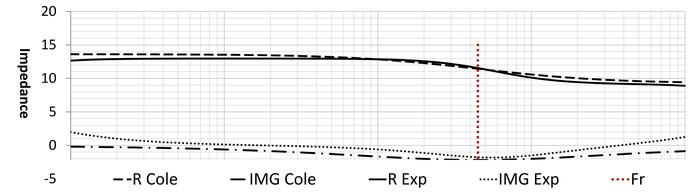
In order to assess the performance of the EIT system, the Sussex EIT board and E-phantom are directly connected to the 85 electrodes as shown in Figure 2(b). In practical we also inserted RSC models of the carcinoma, fat and stroma tissues in different locations to simulate the electrical properties of different tissues (with the RSC value based on [5]), then we constructed a tomographic image.

Step-1: The average SNR of 82.28dB with a max and min value of 91.06dB and 76.42dB was achieved. An average modelling accuracy of 99.47% with a max and min value of 99.97 and 99.91 was achieved.

Step-2: The theoretical result of the impedance measurements has been found by solving the Cole-Cole equation and matched with the experimental results.



Results



Step-3: Comparative images that have been produced by removing the back projection of the image. If we assumed the image without any RSC model is the back projection data, the removal of this data from the image during the reconstruction process will produce the final image.

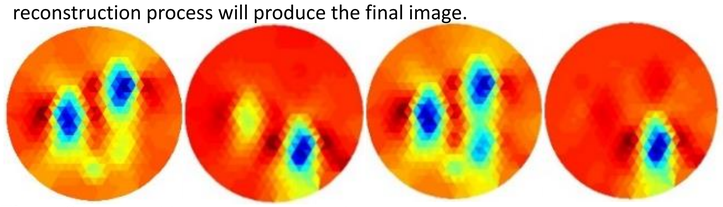


Figure 3. The real (r) and imaginary (imag.) part of frequency-difference images of an E-phantom within three RSC models RSC-1: placed at 17-5 (9 o'clock with dotted line) for carcinoma tissue, RSC-2: placed at 15-21 (2 o'clock with dashed line) for stroma tissue, and RSC-3: 19-30 (5 o'clock with lined) for fat tissue for 1MHz, 3 MHz respectively.

Discussion

One of the main achievements in this study is that, due to the fact that this study was done in a Sussex EIS system for more than 100 times, the output results and image reconstruction results could be precisely controlled and thus was always consistent regarding to the value of SNR and modelling accuracy. Also shows how important is the use of E-phantom in order to make sure new factors have not come to take the place of the performance of the system as will decreases the accuracy of the data.

This study uses an electrical mesh phantom, in contrast to the use of a physical phantom, to mimic an electrical impedance distribution of biological objects for comparison of different methods to improve the numerical inversion and EIT hardware and for validation of the inverse impedance image evaluated. The impedivity data extracted from injection currents and voltage measurements in the EIS system when the RSC models are placed between electrodes in the E-phantom is compared with the impedance results that are determined using the Cole-Cole equation in order to assess the performance of the image reconstruction algorithm. This means simulating the impedance of different physical phenomena at different frequency points.

Implications and future research

The preliminary results have demonstrated that the E-phantom can be very effective as a clinical prototype for QA assessment and future certification. The purpose of the phantom is intended for system validation and performance testing during all phases of the clinical trials: pre-trial, during trial and future clinical derivatives.

References

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